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Page One Title

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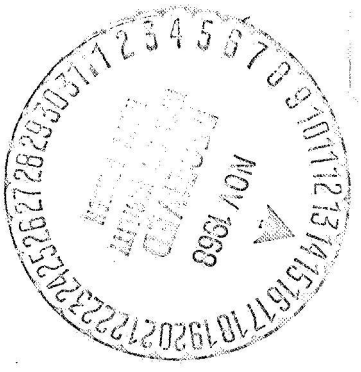

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INVESTIGATION OF NON-CYLINDRICAL Z-PINCH IN CURRENTS ABOVE 1 MILLIAMPERE

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ABSTRACT. The results of studies of the dynamics of plasma focus and its associated emissions, carried out on an apparatus with a 66 cm anode and a condenser capacity of 576 microfarads, are summarized in this report. The two-dimensional problem used to study the characteristic parameters of plasma focus is formulated. The basic experimental results are interpreted under the assumption of high-density plasma in the focus, heated to thermonuclear temperatures.

In recent years the development of efforts in the investigation of self-compressed discharges of the "plasma focus" type is related to many factors which have stimulated research into the area of superdense high-temperature plasma. Using equipment of rather simple design, not requiring a complex vacuum system, and unique with respect to the frequency and energy characteristics of the condenser systems, it is possible to produce plasma with the energy content recorded in one unit of volume. For this reason it has become possible to conduct various physical investigations related to the use of plasma focus as sharply localized sources of neutron and X-ray emission, high pulse pressures, etc. [1-6]. The present report summarizes the results of investigations in the dynamics of plasma focus and its associated emissions on the type of apparatus described earlier [2], but with the diameter of the anode increased to 66 cm and with the capacity of the condenser system increased to 576 microfarad. The statement of a two-dimensional magnetohydrodynamic problem, to be used to study the characteristic parameters of plasma focus observed in the experiment, is formulated. The basic experimental results are interpreted under the assumption of a high-density plasma in the focus, heated to thermonuclear temperatures. /1* /2

*Numbers in the margin indicate pagination in the foreign text.

The calculations of the unidimensional magnetohydrodynamic problem, on one hand, have revealed the role and importance of various dissipative processes in moving plasma, and on the other, by comparison with the experiment, have made it possible to evaluate the effect of "linear mass" losses [7]. These calculations have shown that the basic phenomena (production of neutrons, soft X-ray emission, greater plasma compression . etc.) should be expected after the moment of accumulation of the convergent cylindrical face. The maximal density of the plasma and the temperature peaks are the result of the interaction (collision) of the shock wave reflected from the axis with the plasma cloud (piston) accelerated toward the axis. The maximal compression of the plasma is of the order of 100, while the absolute temperatures are 1-2 kev, assuming that the initial radius is at least one-third the radius of the anode. It is natural to interpret the latter as a loss of greater than 90% of the "linear mass". Within the framework of the unidimensional problem, the most striking divergence of the theoretical calculations from the experimental data is seen by comparing the characteristic times and dimensions of the region where the parameters of the plasma are the highest. The time from the calculations is approximately one order less than that measured in the experiment, while the dimensions are inversely proportional.

The calculations have shown that the velocity of the plasma beyond the face of the convergent shock wave and in front of the face of the reflected wave is virtually constant, and that the role of breaks in the electron and ion temperatures is great. However the effects of the finiteness of plasma conductivity, taken within reasonable limits, has been shown to be slight, particularly for the description of the plasma parameters in the near-axial region. These calculations revealed the important roles of ionic heat conductivity and viscosity of plasma. Electron heat conductivity is also considerable, but this was known before these calculations were undertaken. The role of ion heat conductivity is very important during the stage of shock wave reflection, and the analysis of it resulted in a several-fold reduction in the maximal ion temperature.

Efforts are now being made to carry out two-dimensional magnetohydrodynamic calculations which preserve the cylindrical symmetry of the problem. On the /3
basis of unidimensional calculations, it is convenient to simplify the problem with respect to the calculation of dissipative processes. The necessity to calculate ion viscosity is quite clear, since the structure of the face of the shock wave and its characteristic thickness are very important. Furthermore, it is impossible to carry out continuous calculation through the shock disturbance without considering viscosity. In the system of calculations employed, plasma viscosity was treated, for simplicity, as a second viscosity with the addition of the known path link of the particles discharged in the plasma. The calculation of the first (displaced) would have been very difficult, and the second viscosity probably satisfies the necessary requirements quite well. Plasma conductivity was assumed to be infinite, and the other dissipative processes, including the difference in electron and ion temperatures, were disregarded. Corrections for the role of these and other processes can be made qualitatively on the basis of the results of unidimensional calculations. The initial moment of time for the two-dimensional calculation was established on

the basis of the experimental configuration of the current cloud at some intermediate moment of time, while it is still rather far from the axis, but is nevertheless located as a whole between the front electrodes. At this moment of time the kinetic and heat energy of the plasma in front of the cloud can be disregarded, since they subsequently increase sharply. Magnetic pressure, expressed through the experimentally measured total current, is equated to the gas-dynamical throw of the plasma pulse and is the basic boundary condition of the problem. The macroscopic normal velocity component of the plasma is always equal to zero on both electrodes and on the axis, which eliminates all other boundary conditions in the given approximation.

The first calculations, carried out in the statement of the problem set forth above, indicated that the plasma velocity in the axial direction toward the cathode was not less than the plasma velocity in the radial direction. Near the cathode, due to the effect of reflection of the shock wave from it, peculiar "pockets" are formed which exclude the ever newer portions of gas from the gas-dynamical process, thus verifying our theories concerning "linear mass" loss. This process appears to be significant even before the forward part of the cloud reaches the axis. The basic calculations of the processes in the near-axial region, which should yield the characteristic dimensions and life time of the plasma in the compressed state, and which should reveal the dynamics of plasma focus, are now being worked out. The authors hope to summarize the quantitative results in the form of graphs and tables before the conference begins. /4

The usual electronic measurements were made during the experiments on the apparatus with increased energy content together with the development and use of the various methods for investigating the dynamics of the compressed state and its associated emissions. We oscillographed I, V, and j, as well as the current flowing through the near-axial region of the discharge chamber, I_r.

Since the plasma cloud becomes compressed due to the electrodynamic forces of the fundamental current, there must be a strong relationship between the value of this current near collapse I_c and the intensity of neutron production, which characterizes the parameters of the compressed plasma. As I_c increases on the various Z-pinch systems, the intensity of neutron production also increases sharply. Collapse usually occurs as the current drops due to rapidly increasing dynamic inductive resistance, when the condenser system ceases to be the basic source of energy causing the current to flow. During this time, energy which is stored up in the inductance of the discharge circuit is consumed in the compression of the plasma cloud. The fact that I_c depends but little on the initial inductance of the discharged circuit when the initial conditions are constant (gas pressure in the chamber p_o and voltage on the circuit V_o), is curious indeed. Figure 1 shows several oscillograms of I and V for various initial inductances L_o, where p_o equal 1 torr (D_2 + 1% N_2) and V_o = 18 kv. A large current flow, of the order of 1 megaampere, is necessary to achieve high compression velocities for the purpose

of producing a high-temperature accumulation zone. The indicator of the effective use of this current is the depth of its drop during collapse, which characterizes the velocity and extent of compression, i.e. the density of the current) at the moment of accumulation (similarly as in [8]). Figure 2 shows the decreasing dependence of neutron production on I_c for a series of discharges under identical initial conditions. When the values of I_c are equal, neutron production is greater for discharges with lower pressure. (Possible variations/5 in the initial conditions presume conformity of the dimensions of the chamber and of the initial gas pressure with the electronic properties of the discharge circuit).

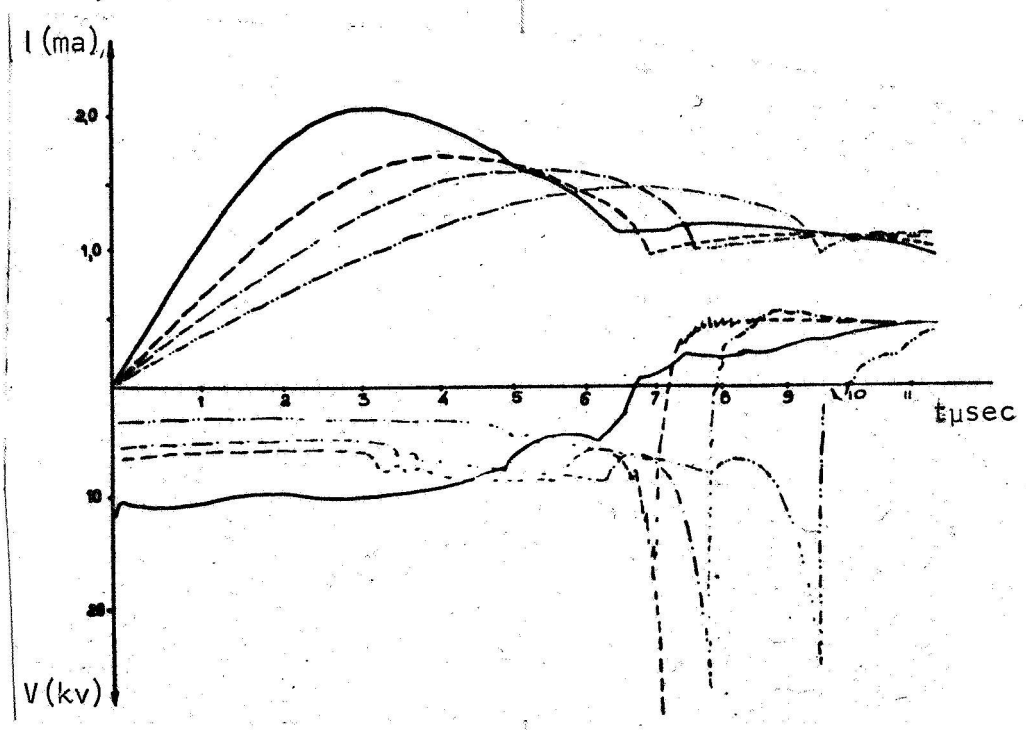

Figure 1. Oscillograms of I and V for Various Initial Inductances L where p_o = 1 torr D_2 and V_o = 18 kv.

Several experiments have been conducted for the purpose of determining the size of the current flowing through the central zone of the discharge. The measuring insert in the positive electrode shown in Figure 3 was used for this purpose. Differentiated Rogowski loops (4), the signals from which were directed to the plates of the oscillograph, were placed in annular channels (1) of copper conductor (2) and shielded with thin stainless steel screens (3). The magnetic field of the current cloud, entering the zone encompassed by the measuring annulus, penetrates into the annular channel at a rate depending on the thickness and conductivity of the steel screen and on the volume of the cavity containing the measuring loop. The theoretical sensitivity and frequency characteristics of the loops were checked by calibrated tests, both on a special circuit with a frequency of 2 MHz and a maximum current of about 100 kiloamperes, and also using magnetic probe (5) during the operation

of the discharge chamber. Figure 4 a, b show the oscillograms related to this series of experiments. Figure 4, a is the current I_r passing through the central zone of an electrode with a diameter of 4 cm and combined with the total current I and voltage in the chamber (Figure 4, b shows the typical oscillograms of the I_r currents through zones with diameters of 4 cm and 8 cm for discharges with different neutron outputs. The initial displacement of the signals caused by the motion of the current front is clearly visible. These experiments lead to the conclusion that a current will pass through a zone no greater than 4 cm in size, which corresponds to the total current at that moment of time (~ I_c). The time that the current remains in this zone is limited to a few tenths of a microsecond, and neutron emission will drop off during this interval. The increase in the duration of the I_r signals on the oscillograms corresponding to the lowest neutron output is apparently caused by the more vigorous evaporation of the surface of the screens during lower compression velocity. Neutron output is independent of the amplitude of the current in this zone, but it correlates well with the velocity of the cloud determined according to the displacement of the I_r signals (Figure 5). In constructing the graphs (Figures 5 and 7), only the oscillograms of those discharges whose symmetry of compression was established according to hard X-ray photographs, were processed. The fact that the points related to the various initial V_o, where p_o = Constant, fit into the general relationship is worthy of attention. Initial pressure is an independent parameter illustrating the proportionality of neutron output to the square of the density.

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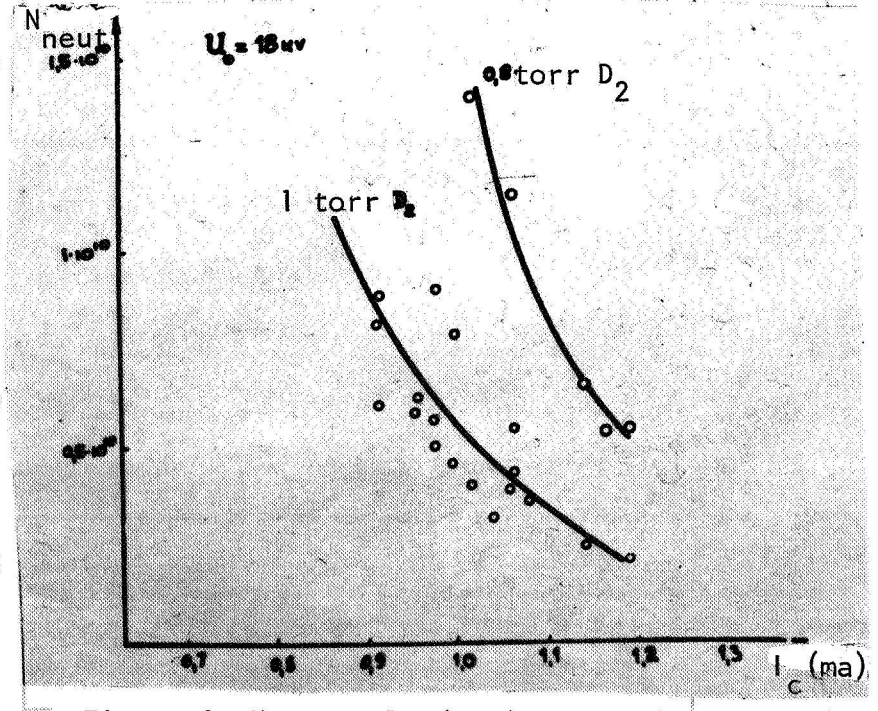

Figure 2. Neutron Production as a Function of Current at the Moment of Compression (I_c).

Preliminary tests conducted with the insert, which limited the measurement zone of the I_r current to 1 cm in diameter (Figure 6), on the other hand, reveal a close relationship between the amplitude of the current in this zone and neutron output (Figure 7).

Renewed current density through this zone results in the vigorous evaporation of the steel screen and the formation of metallic plasma which shunts the resistance of the screen. This greatly delays the signal of the measuring loop (see also Figure 4 b) and poses a

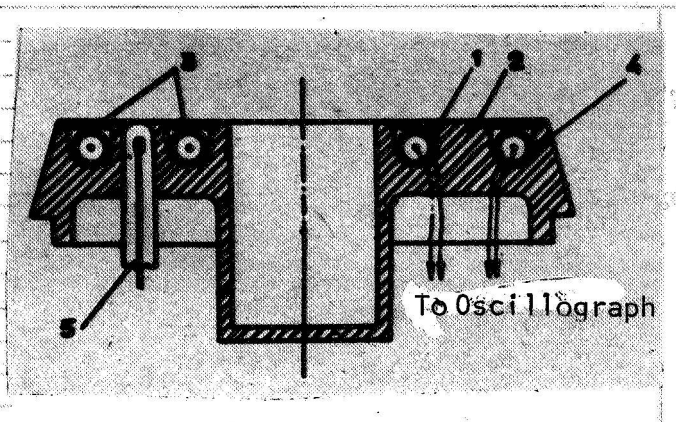

Figure 3. Diagram of Measurement Insert.

considerable limation to the application of such method.

During the investigation of the emissions occurring in the apparatus with plasma focus, a peculiar contradiction was observed: on one hand, the amount of nuclear reactions observed during the discharge and the parameters of the plasma focus give evidence of the primarily heat mechanism of the interaction of deuterons [2, 3], and on the other hand, the energy and density of the hard X-ray emission from the surface of the electrode prompts the assumption that a considerable part of the current is transferred by electrons accelerated to ~ 100 kev. The electrical field in which the electrons are accelerated should also accelerate deuterons, thus explaining the amount of nuclear reactions observed. A similar situation, but with an even greater degree of ambiguity in the mechanisms of the formation of both types of emission, was observed during the investigation of cylindrical Z-pinches. An increase in the integral production of neutrons to a level greater than 10^{10}, with a simultaneous increase in stability and localization in space, improved the capabilities of the systems with plasma focus to reveal the nature of the observed emissions. The first steps in this direction were taken in [9, 2]. In the present work we have attempted, in parallel with the computerized calculation of the two-dimensional problem, to explain experimentally the relationship between the spatial and time characteristics of the region which emits soft X-ray emission (as the outward manifestation of plasma with high πT), and of the zone in which the (d--d)- reactions take place at a high rate. The analysis of these results must agree with the data obtained from the complex investigation of hard X-ray emission. /7

The program of the experimental studies included the following measurements.

1. Plasma focus was photographed by a camera obscura in the light of soft X-ray emission. Simultaneously, the same image of the pinch was turned around in time using a rotating film disk with an electron-sensitive emulsion [1].

2. The position on the discharge axis of the "center of gravity" of the zone emitting neutrons and its length along the axis were found from indicators of point detectors with an active element in the form of a plate of natural metallic uranium. Three or four such indicators with end-window β-counters were arranged along the axis of the camera at known distances. The true excess of the activity of the detectors over the background for an output of greater

than $5 \cdot 10^9$ neutrons per pulse makes it possible to make the given measurements for each discharge. When a relatively simple apparatus is being used this method yields reliable quantitative results. One disadvantage, however, is the fact that the results cannot be interpreted uniquely because both the stationary long points source and the point source which moves along the axis can produce identical effects.

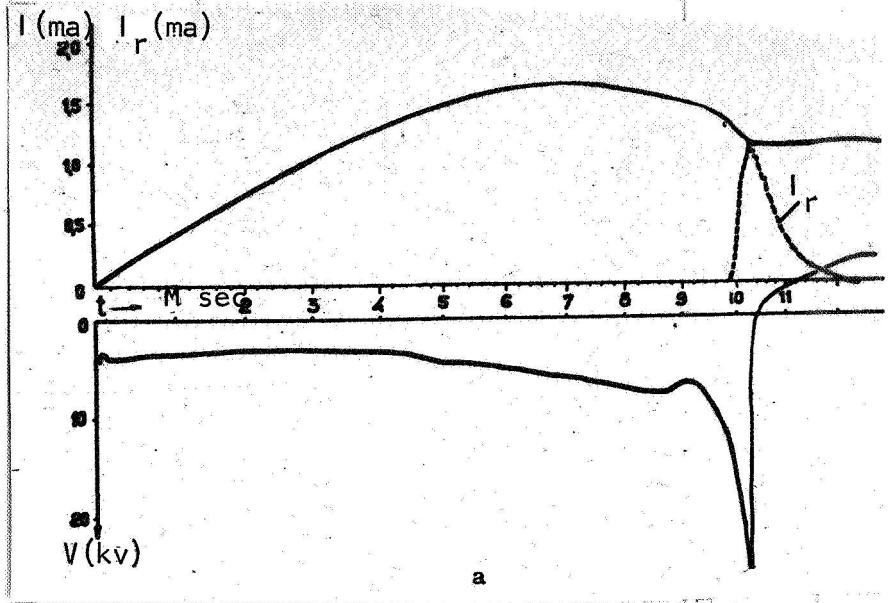

Figure 4 a. Current Through Central Zone of Electrode 4 cm in Diameter, Combined with Total Current and Voltage.

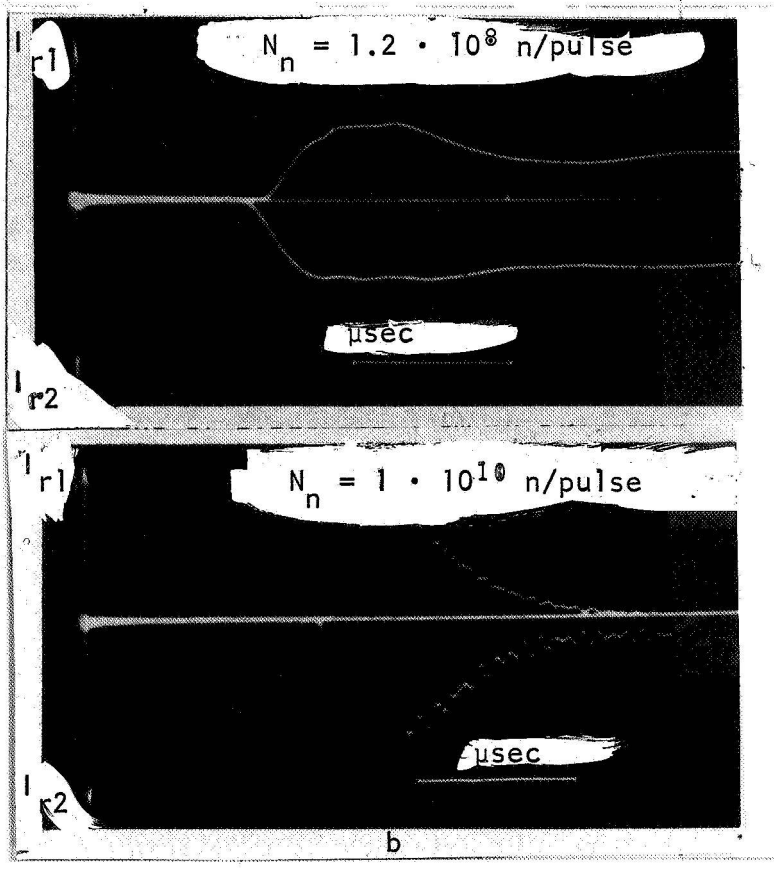

Figure 4 b. Typical Oscillograms of Currents Through Zone 4 cm in Diameter (I_r) and 8 cm in Diameter (I_{r2}) for Discharges with Various Neutron Output.

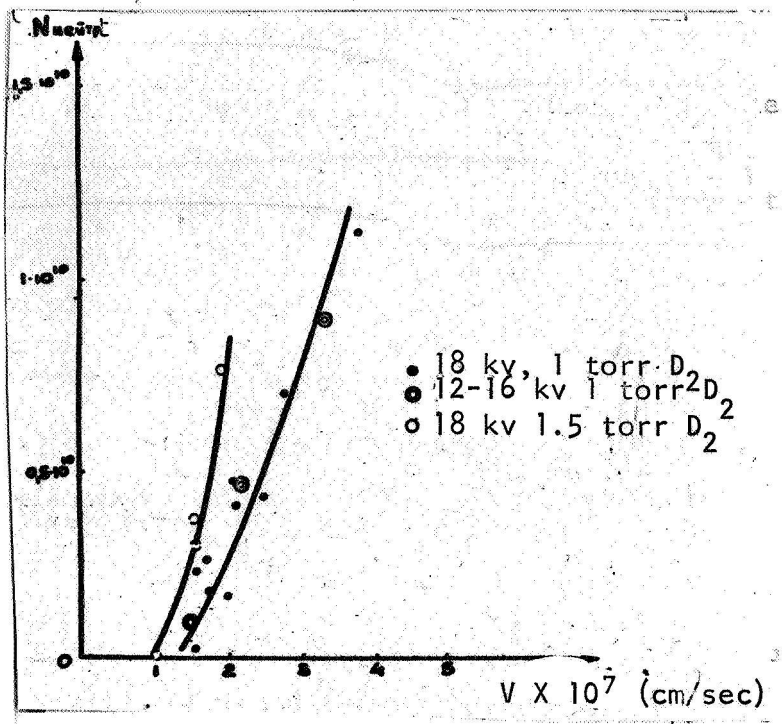

Figure 5. Neutron Production as a Function of Velocity of Current Face.

3. The aforementioned uncertainity can be resolved by using a multislit collimator, which determines the time location of the neutron source. The collimator with a photomultiplier and 6 laminar scintillators, the emission of which is conducted by light conductors to a common photocathode, is installed in a horizontal plane near the side wall of the camera. Time resolution was 10^{-8} sec and spatial resolution was 1 cm. The bottom slit of the collimator scanned the cross-section of the chamber at a height of 0.5 cm above the anode, the distance between the slits was 1.5 cm, the height of the slit was 3 mm with a horizontal dimension of 30 mm. Comparative analysis of the modulation of the signals from the FEU (photomultiplier) of the collimator and from the scintillation detector, which records the complete neutron emission, makes it possible to evaluate both the axial velocity of the source and its length.

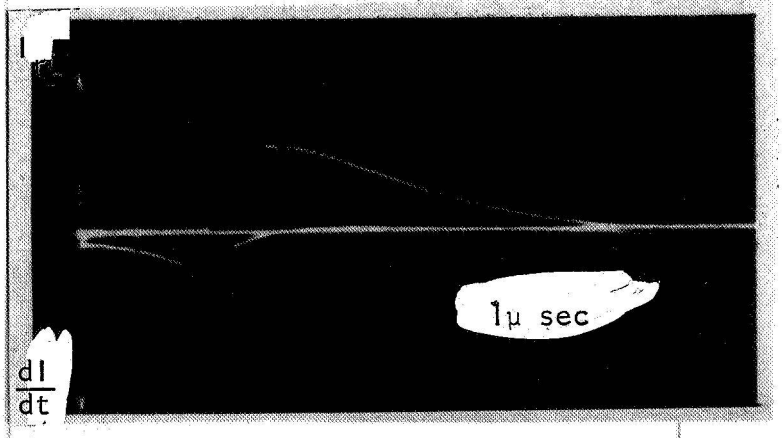

Figure 6. Current Through Central Zone 1 cm in Diameter.

4. A shift of the neutron source in space affects the form of the signals of the scintillation detectors, which are placed at angles of 0° and 180° to the direction of motion (analysis of velocities by transit time). The collimated detectors in the lead screens were placed at distances of 6.7 m at angles of 0°, 90°, and 180° relative to the discharge axis (0° is the direction to the cathode). This distance is adequate for the accurate division of the hard X-ray emission and neutron pulses in time. The first pulse is used to test the synchronization of the beams of the oscillographs, and to establish the nature of the relationship between the intensities of both forms of emission.

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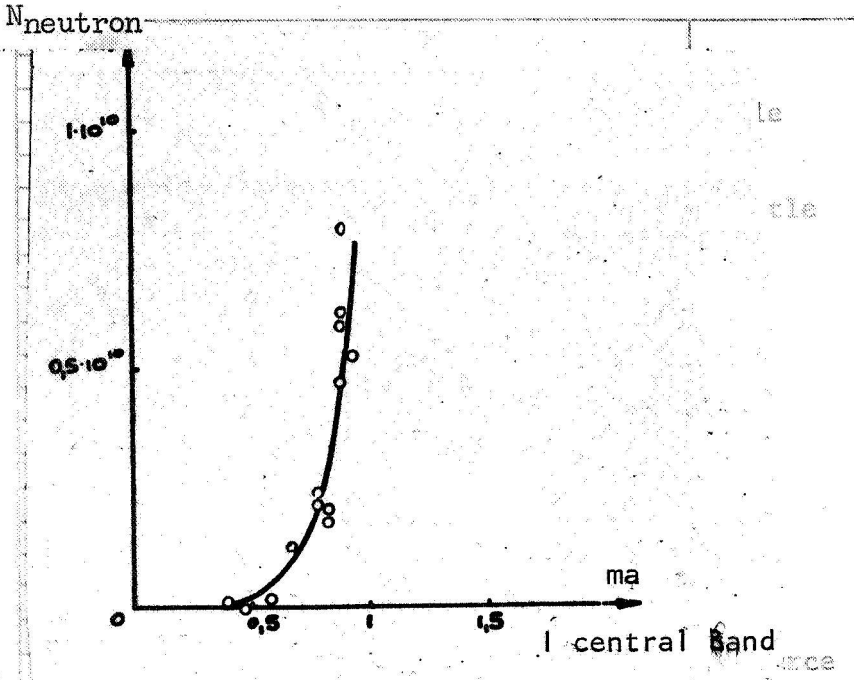

Figure 7. Neutron Production as a Function of Current Amplitude in The Central Zone 1 cm in Diameter.

The results obtained can be briefly summarized as follows.

The time integral picture of the distribution of neutron emitters along the axis should be identified with a source 5 to 7 cm in length, whose "center of gravity" varies from 1 to 1.5 cm above the plane of the anode.

Accurate calculations of the intensity distribution of the neutron emitters along the axis which satisfy the indicators of all the counters at the same time, indicate a spindle-shaped source close to the roughly approximated shape found earlier in [9]. A comparison of these results with photographs of the pinch in the light of soft X-ray emission indicates that the longitudinal dimension and the position of the neutron source agree satisfactorily with the corresponding spatial characteristics of the compression zone of high-temperature plasma. (An increase in the sensitivity of the method during the recording of soft X-ray emission was brought about by the introduction of small additives of nitrogen, ~ 1% by number of particles, to deuterium). By photographing the image of the pinch, reduced by a factor of 130, on rotating film we were able to establish that the region emitting soft X-rays moves along the axis of the chamber from the anode to the cathode. Figure 8, a and b shows the photographs of the pinch through an aperture 20μ in diameter on the revolving film (Figure 8a) and through an aperture 240μ in diameter (Figure 8 b) on stationary film. The photographs in X-rays were taken from diametrically opposed directions. The horizontal band was caused by near-electrode emission and the direction of the time base is indicated by the arrow. These photographs were taken for p_o = 1.5 torr (D_2 + 1% N_2), U_o = 20 kv and a neutron output of $1.3 \cdot 10^{10}$ n/discharge. By measuring the slope of the image of the pinch caused by the rotation of the film, it is possible to estimate the velocity of the plasma in the axial direction. This velocity was of the order of 10^8 cm/sec. This result agrees with the velocity of the zone which emits neutrons as determined by calculating the shift of the signals from the scintillation detectors oriented at angles of 0° and 90°. (The calculation was made for the very discharge in the theory of the model of a "mobile reactor"). /9

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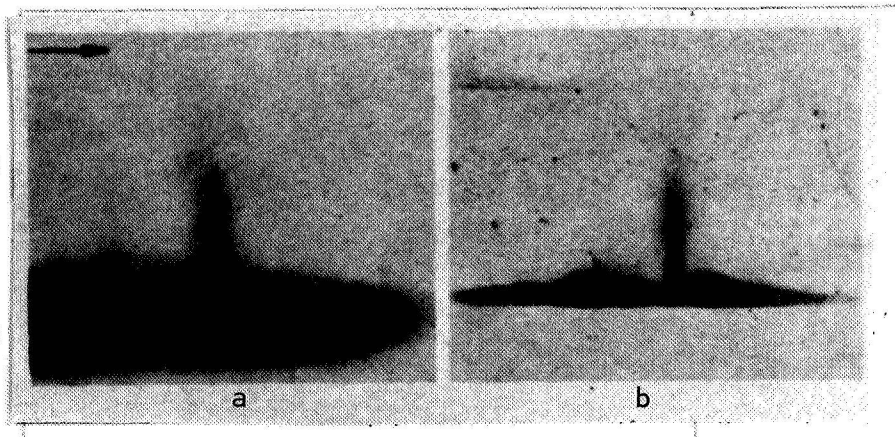

Figure 8. Photographs of Pinch in Soft X-rays on Rotating (a) and Stationary (b) Film.

In Figure 9 we see the oscillograms of the signals of the scintillation detectors (0° and 90°) during tests with a flat anode insert. Rear splitting of the insert material and a powerful pulse of hard X-ray emission with a moderate amount of neutron production were noted in these discharges. Appropriately, practically no displacements or variations in the shape of the signals of the neutron pulses showed up on these oscillograms. The latter condition is incompatible with the theory concerning the acceleration of a considerable amount of deuterons in the very same region of the discharge where electrons are accelerated to an energy of about 100 kev. In Figure 10, a and b we see the analogous oscillograms for discharges accompanied by weak X-ray emission (the central part of the anode has a depression) for relatively high neutron outputs. In these cases, in the absence of a displacement at the beginning of the neutron pulse, a displacement of the peaks is sometimes observed, which is accompanied by a distortion in the shape of the signals. The greatest displacement of the peaks similar to those in Figure 10 a did not exceed $3 \cdot 10^{-8}$ sec. For Figure 10 b, this displacement was $2 \cdot 10^{-8}$ sec. The velocity of the neutron source corresponding to such displacements did not exceed 10^8 cm/sec. This velocity is apparently a function of the shape of the convergent cloud immediately in front of the accumulation.

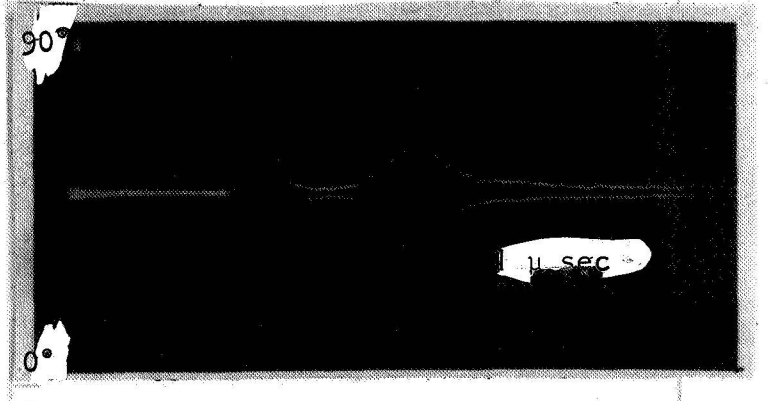

Figure 9. Oscillograms of Signals From Scintillation Detectors with Flat Anode Insert.

If we examine the compression of a conical cloud with a large aperture angle, then we will see that a stream of plasma emerges from the apex of the cone during accumulation, and that the velocity of this plasma stream may exceed the phase velocity of convergence of the cloud along the axis. In this case high temperature and density are present only at the points of convergence of the cloud as the separated stream rapidly cools. Various particles will take part in the formation of a neutron source in the very same way as time passes. In this case the neutron signals, recorded at various angles, should be identical.

If the shape of the cloud is such that the initial velocity of the stream corresponds to the phase velocity of accumulation along the axis, then the high temperature and density of the focus moving along the axis will be maintained by the compression moving at the very same phase velocity. In this case, the corresponding variations in the signals will occur for the various angles of observation. Under actual conditions, both variations should be observed due to the variable curvature of the cloud, and the precise picture of these variations will be obtained toward the end of the computerized calculation of the two-dimensional problem.

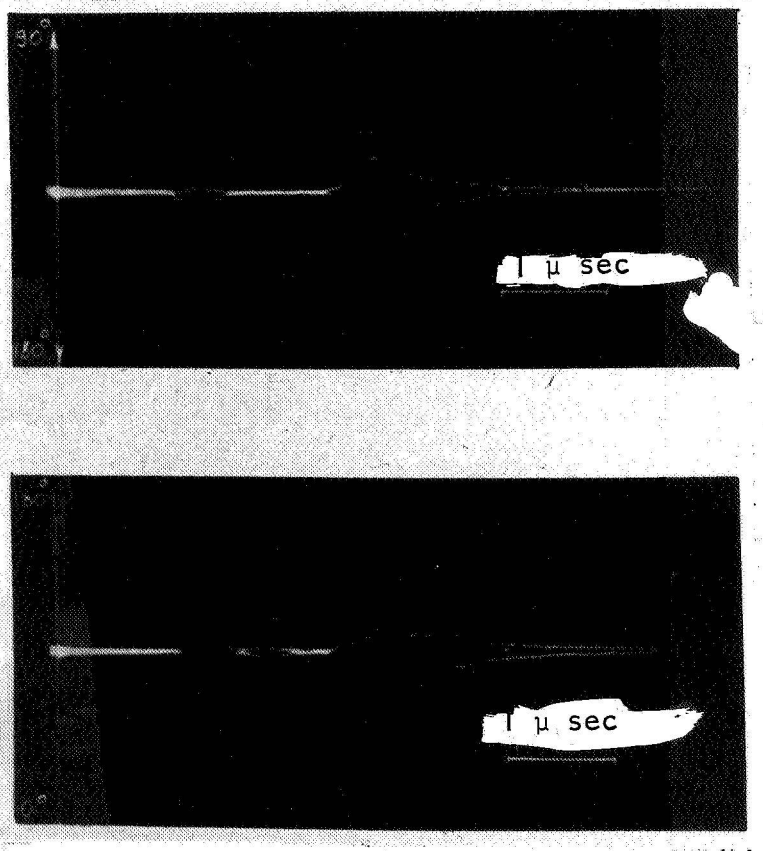

Figure 10. Oscillograms from Scintillations Detectors for Weak X-ray Emissions.

The absence of a direct quantitative relationship between hard X-ray and neutron emissions in connection with the results described above enable us to separate these effects in space, considering that the basic part of the accelerated electrons is formed in the near-anode layer of the metal vapors, while the neutron emission is formed in the moving plasma focus.

We investigated hard X-ray emission basically on an apparatus of the type described in [2], and then on an apparatus with a condenser system of increased energy content. We were not able to establish the qualitative difference in emission characteristics, but the energy of the X-ray pulse was several times greater on the large apparatus and exceeded 10 joules in individual discharges. It should be noted that the maximum quantities of X-ray emission and rear splitting of the anode material were observed under specially selected conditions, where the pinch was small in altitude and pressed to the surface of the anode. The effect was much weaker under usual operational conditions.

We used thimble chambers, a calorimeter, scintillation detectors, dosimetric films, a camera obscura, and a mercury thermometer for investigating emission. The calorimeter, screened with 3 mm of aluminum, consisted of 25 lead plates 2 mm in thickness and 25 copper-constantan thermocouples. The

sensitivity of the thermopile was 10^{-4} C°. The energy spectrum of quanta was evaluated by the filter method using ionization dosimeters and photographic films. The direction diagram of emission was obtained on the basis of the indicators of the dosimeters, which were arranged at angles of 0°, 30°, 60°, 82°, and 180° to the axis of the chamber. The shape and duration of the X-ray pulses was determined using scintillation detectors with a time resolution of < 20 n/sec. The emission energy during discharges with high output was /11
determined with a Beckman mercury thermometer. In these cases, the mercury was heated to 0.1 C°. The surface of the anode was photographed from above (from the cathode) in hard X-rays penetrating 3 mm of aluminum by a camera obscura with an aperture ⩽ 1 mm.

The tests established that hard X-ray emission with a duration of 0.1-0.2 μsec and with a total energy of up to 5 joules is formed on the anode and in the latter of the vapors of the anode material. The energy of the quanta encompasses a broad range and the maximum of the spectrum corresponds to an energy of 40--60 kev. The spatial distribution of emission differs from the direction diagram of the X-ray tubes with a massive anode: there is a lack of spherical symmetry of "back" emission. Emission in the 90° direction, i.e. along the surface of the anode, is most weakly absorbed. During ordinary discharges, the average emission dose in the 0° direction is 0.04 p, and in the 90° direction it is 0.1 p at a distance of 50 cm from the center of the anode. The results obtained enable us to conclude that at the moment of greatest compression of the pinch in the immediate vicinity of the center of the anode, the electrons are accelerated to an energy of about 100 kev.

When the duration of emission is $\Delta t \sim 10^{-7}$ sec and the quantum efficiency of the copper anode is $\eta \sim 10^{-3}$ (for average quantum energy $W_\Gamma \approx 60$ kev), the observed emission energy Q should be provided by current I of the order of the total current at the moment of compression I_c. Actually, $Q = \frac{I\Delta t}{e}\eta \cdot W_\gamma$ and for Q ≈ 5--6 joules, I is ~ 10^6 A, which agrees quite well with I_c. The size of the zone of intensive emission of the anode in the X-rays varies in a broad range from 0.1 to 1 cm^2. Under the effect of electron bombardment, a crater with individual depressions or grooves is formed on the anode. A layer of metal is separated from the exterior of the anode insert [10], which is identical in shape to the spot on the X-ray photograph. The similarity of the cleavage and the X-ray image was strengthened and acquired high definition in shape during operation on the new apparatus (Figure 11, a and b). The photographs included in the present work were taken on a apparatus with an anode 66 cm in diameter with the following discharge parameters: p_o = 1 torr D_2, W = 73 kilojoules, $I_c = 0.9 \cdot 10^6$ A, $N_n = 5 \cdot 10^9$ n/pulse. The energy of hard X-ray emission was approximately 8 joules. With consider- /12
ation of the actual direction diagram, this energy should be increased by a factor of 1.3--1.5 (the energy equivalent of 1 roentgen ≈ $3 \cdot 10^{-4}$ joules [2]). These photographs show the peculiarities in the behavior of the pinch at the point of contact with the surface of the anode more graphically than before. The anode cross-section (Figure 11 a), the shape of the cleavage (Figure 11 b) and the trace of the pinch on the surface of the anode (Figure 11 c) have the

shape of an unwinding right-hand spiral when viewed from the cathode. We may assume that the end of the pinch, having an instantaneous contact area with the anode of a few mm^2, moves along the spiral, causing the observed effects. The displacement of the end of the pinch is caused by the rapid evaporation of the anode material, with the result that a "cushion" of metallic vapor with low conductivity is formed. (This phenomenon is similar to the electrical burn-out of a metallic conductor). The increase in resistance causes the formation of a longitudinal electrical field within which electrons are accelerated, promoting the further vaporization of the anode material. A shift of the pinch to a zone with lower vapor density restores conductivity, but causes vaporization at the new point of contact. When the current densities characteristic of energy compression are high, the process of vaporization is continuous when the end of the pinch is in motion. Otherwise, we may observe discreteness of the spots (chaotic state of "splitting"), which also occurred on the apparatus with low energy content, fogging the recorded rotation. Since the duration of the hard X-ray emission recorded by the scintillation detector was $\sim 10^{-7}$ sec, the average velocity of the end of the pinch in the model under investigation was close to the characteristic hydrodynamic velocity, or (1--5) $\cdot 10^7$ cm/sec. A deflection in the pinch near the contact with the electrode, deforming the strong lines of the magnetic field, can result in the appearance of new components, both of the field and of the current (H_z, H_r, j_r), which produce azimuthal and axial components of pondermotive force. It is possible that the magnetic field of the earth, strengthened by the compression of the current cloud, plays a definite role in the observed rotation. In the latter case, a right-hand rotation should be observed. It may be said that the pulse pressure developing during bombardment of the anode by accelerated electrons is capable of causing "rear splitting". /13
For this purpose we will equate the current density of the energy of the vapors leaving the anode to the current density of the energy of the fast electrons: $p \cdot v_n = n_e \cdot v_e \cdot W_e$, where p is the pressure at the point of contact, $v_n = 5 \cdot 10^6$ cm/sec is the velocity of the vapors determined by photoscanning the cross-section of the pinch, n_e, $v_e \approx 2 \cdot 10^{10}$ cm/sec, $W_e = 100$ kev are the density, velocity, and average energy of the electrons, respectively. Assuming that the current of the fast electrons is equal to the total current I_c when the area of contact is $\sim 10^{-1}$ cm^2, we obtain $\sim 3.10^{15}$ cm^{-3} for n_e. Then for p we find $\sim 2 \cdot 10^6$ atm, which is quite adequate for the development of splitting. This calculation verifies the estimation of the energy content of plasma focus given in [10], since, in the final analysis, both mechanisms characterize the density of the magnetic energy on the boundary of the pinch.

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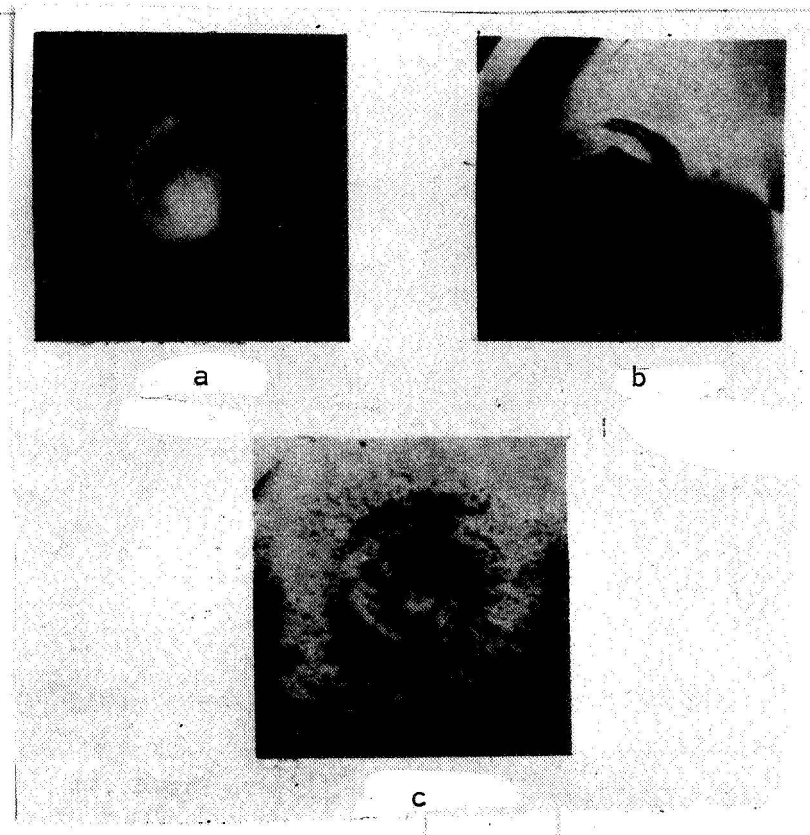

Figure 11. a) Surface Emission in Hard X-rays (camera obscura with an Aperature of 1 mm). b) Shape of Splitting on Exterior of Anode. c) Result of the Effect of the Pinch on the Interior Surface of the Anode. The Photographs Correspond to a Discharge With p_o = 1.0 torr D_2, W = 73 kilojoules, $I_c = 0.9 \cdot 10^6$ A, and with Neutron Output $N_n = 5.10^9$.

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